Impulsive Noise Suppression via Adaptive Filtering

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Introduction: Wide area surveillance is a common task for many of the nation's defense agencies. Coverage needs to be persistent 24 hours a day and through varying interference environments. High Frequency Over-the-Horizon Radar (HF-OTHR) is capable of providing wide area coverage that is on the order of hundreds of thousands of square kilometers. The challenges of using OTHR are manifold. Operating in an often crowded and noisy frequency spectrum (3–30 MHz) coupled with the complex and ever-changing state of the ionosphere presents difficulties higher-frequency radars do not face. In this article we describe a technique for suppressing impulsive noise-like disturbances that often corrupt OTHR data. This new technique is enabled by recent advances in high-speed computing that allow near-real-time implementation of sophisticated adaptive signal processing algorithms.

Background: OTHR is a surveillance radar technology that both the U.S. Navy and U.S. Air Force have used over the past forty years because of its wide area coverage capability and low operating cost.[1] Researchers at the Naval Research Laboratory (NRL) developed one of the first OTHR systems in 1961 called MADRE. Currently NRL is helping to develop advanced OTHR systems while also serving as technical advisors to the Navy's AN/TPS-71 Relocatable OTHR (ROTHR) program which consists of three radar sites providing surveillance coverage of the Caribbean Sea, Central America, and South America. Figure 11 shows a ROTHR receive antenna array and Figure 12 shows the approximate coverage area of the three radars.

OTHR operates by either refracting signals off layers of the ionosphere (skywave) or propagating a surface wave over the conductive ocean that follows the curvature of the Earth. Among the many sources of performance limitation, impulsive noise is a major contributor. Impulsive noise differs from normal noise sources like thermal noise and cosmic background noise in that it is highly transient with very large amplitude peaks. Traditional Gaussian statistical assumptions fail to properly model this type of noise, and therefore normal target detection algorithms may perform poorly, often with very high false-alarm rates. Recognizing that current data models were inadequate, a signal-plus-noise model was developed that can be used to accurately estimate when data has been corrupted by impulsive noise and subsequently filter the data so as to remove the impulsive noise.

Noise Modeling: Atmospheric noise, power lines, and sporadic local interferers such as engine noise are all types of noise sources that are not well modeled by Gaussian probability distributions. Noise generated by these sources is inherently transient in nature (e.g., a single car driving near the array, a single arc from a power line transformer, or a lighting strike from a distant thunder storm). To this end, a probability distribution describing such random processes should possess "heavy tails" to accurately express the probability of an extreme valued random event. The drawback of modeling using heavy tailed distributions is that detector design can quickly become intractable due to complex expressions for probability density functions (PDFs). An alternative to using heavy tailed distributions is to allow a degree of non-stationarity. Simply put, non-stationarity means that the moments or statistics of a random process change (usually with time or space if we are considering a space-time random process).

FIGURE 11
AN/TPS–71 ROTHR receive array.

In the extreme, non-stationarity could be taken to mean that the random process has different statistics everywhere. It is exactly this interpretation that allows us to hypothesize a space-time point process model for the noise field present in OTHR data. The full data model is composed of three independent parts: backscattered energy from targets, background/thermal Gaussian noise, and other noise that appears like impulsive events. The OTHR data is modeled as the combination of two space-time point processes:

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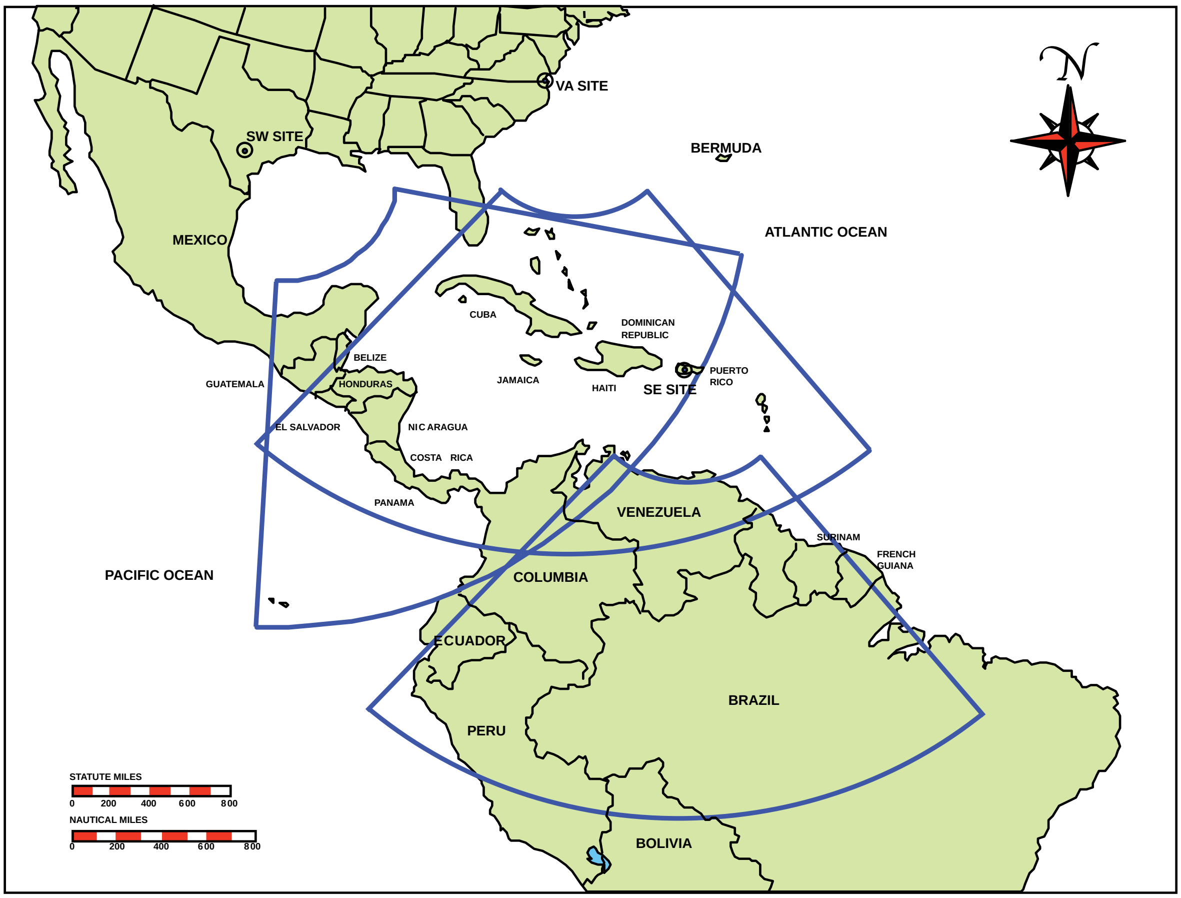

FIGURE 12
Conceptual illustration of OTHR operational environment.

the first models targets and ground clutter (point-like in range-Doppler domain) and the second models impulsive noise (point-like in inverse range-Doppler domain, that is, the fast time–slow time domain before range-Doppler processing). Given this hypothesized data model, modern statistical estimation methods can be used to adaptively filter the impulsive noise.

Adaptive Noise Filtering: Adaptive signal processing describes a method of processing data in such a way that important information is inferred from data in a real-time manner and is allowed to influence the way in which data is processed. More reliable and robust performance is achieved at the expense of slightly diminished peak performance. The adaptive impulsive noise filtering algorithm that has been developed works by first estimating the statistics of target and noise random processes jointly, and then constructing a filtering matrix to recover an estimate of the received data with the impulsive noise removed.

The estimation step requires finding the joint maximum likelihood target range-Doppler power spectrum and noise time-pulse power spectrum estimates. Maximum likelihood (ML) estimation problems are known to be difficult and often analytically intractable. Only recently with the advent of highly parallelized computer architectures have such problems been solvable in near real time. Our solution to the ML estimation problem makes use of a well know statistical algorithm called the expectation maximization (EM) algorithm. Using this iterative algorithm, an ML estimate may be found. Construction of an appropriate filtering matrix is based on finding the minimum mean squared error (MMSE) estimate of the impulsive noise free data. Figure 13 shows the results of applying this algorithm to a set of simulated OTHR data.

An alternative to the model-based maximum-likelihood approach we have described is to systematically identify data samples corrupted by impulsive noise and remove these samples from the data. Simulations and analysis of real OTHR data revealed that the ML approach performed better than several methods previously developed for HF-OTHR data based on extraction and replacement.[2] Additionally, these extraction and replacement techniques are highly dependent on the severity of the impulsive noise corruption and the method used to replace the extracted samples (usually linear prediction).

Conclusion: Non-cooperative interference will always be a problem for surveillance sensor systems. It is possible, however, to minimize its impact on system performance given the correct signal processing. In this article a new technique for solving the impulsive noise suppression problem was presented. In the future, researchers at NRL will continue to push the limits of OTHR technology by developing new and innovative signal processing solutions.

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References

[1] J.F. Thomason, "Development of Over-the-Horizon Radar in the United States," in *Proceedings of the International Radar Conference, Adelaide, Aust., Sept. 3–5 2003*, pp. 599–601.

[2] J.R. Barnum and E.E. Simpson, "OTH Radar Sensitivity Improvement by Temporal Excision of Impulsive Noise," Rome Laboratory, Griffiss Air Force Base, NY, Technical Report RLTR 94-169, Sept. 1994, contract F30602-93-C-0112.

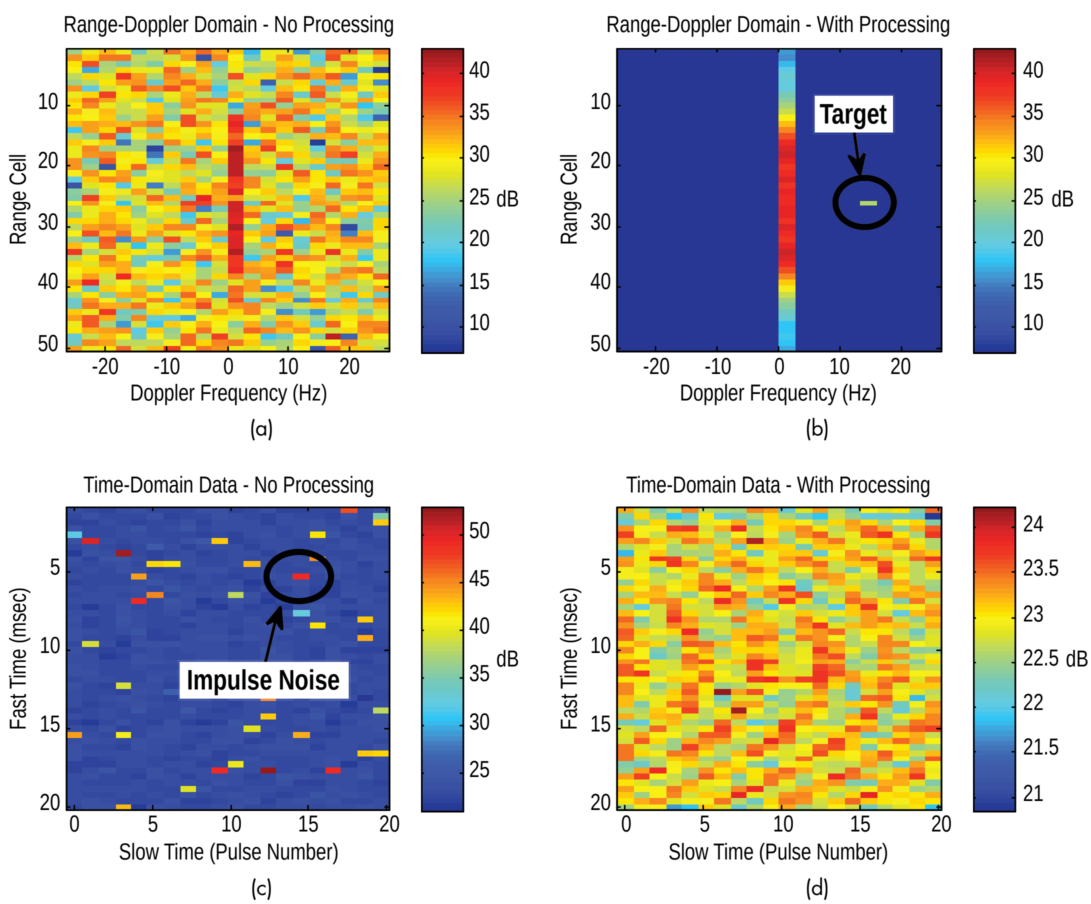

FIGURE 13
Example of adaptive noise suppression technique operating on simulated data. (a) Range-Doppler image with no noise suppression processing; (b) time-domain representation of data, with impulsive noise present; (c) Range-Doppler image after impulsive noise suppression, target can be detected; (d) time-domain data after impulsive noise has been filtered.